NASA Experience with the Shuttle External Tank

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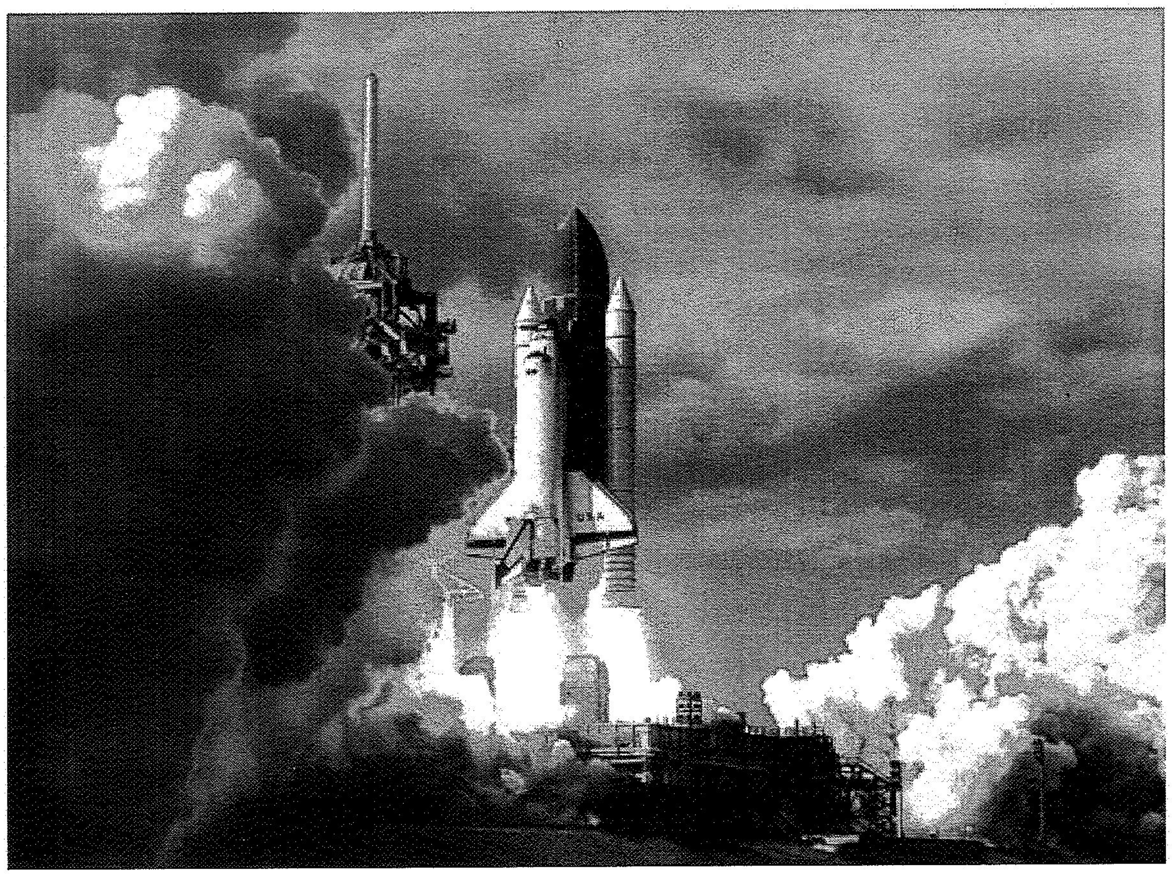

Road Map

IN-16
046 436
P33

- Why a Third Generation External Tank
- Space Shuttle Performance Enhancements
- Super Lightweight Tank (SLWT) Heritage
- SWLT Weight Savings
- SLWT Configuration
- Aluminum - Lithium 2195
- SLWT Key Technologies
- SLWT Snapshots/History
- Intersection Crack Resolution
- SLWT Verification
- Augmented Light Weight Tank (ALWT)
- Summary

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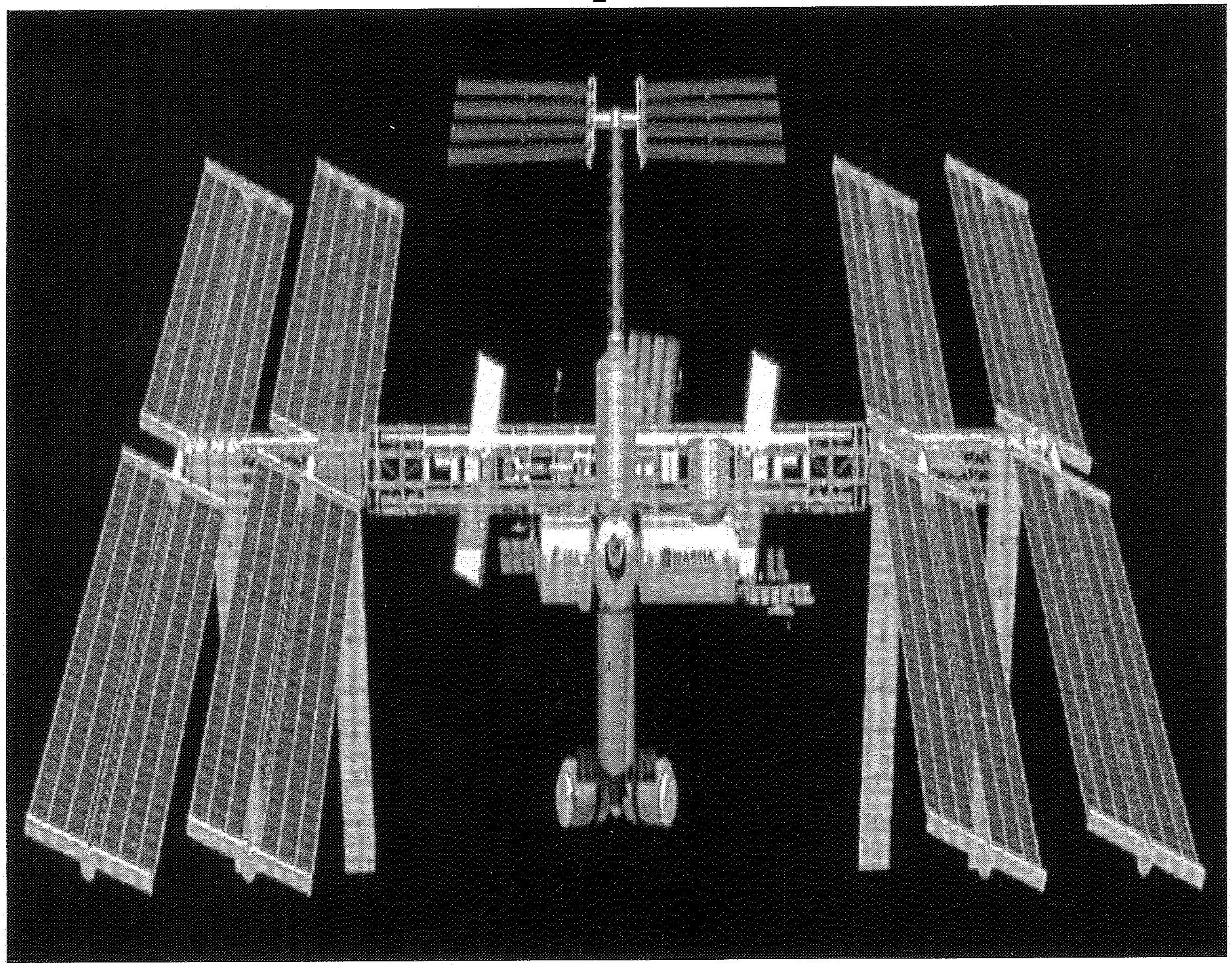
International Space Station



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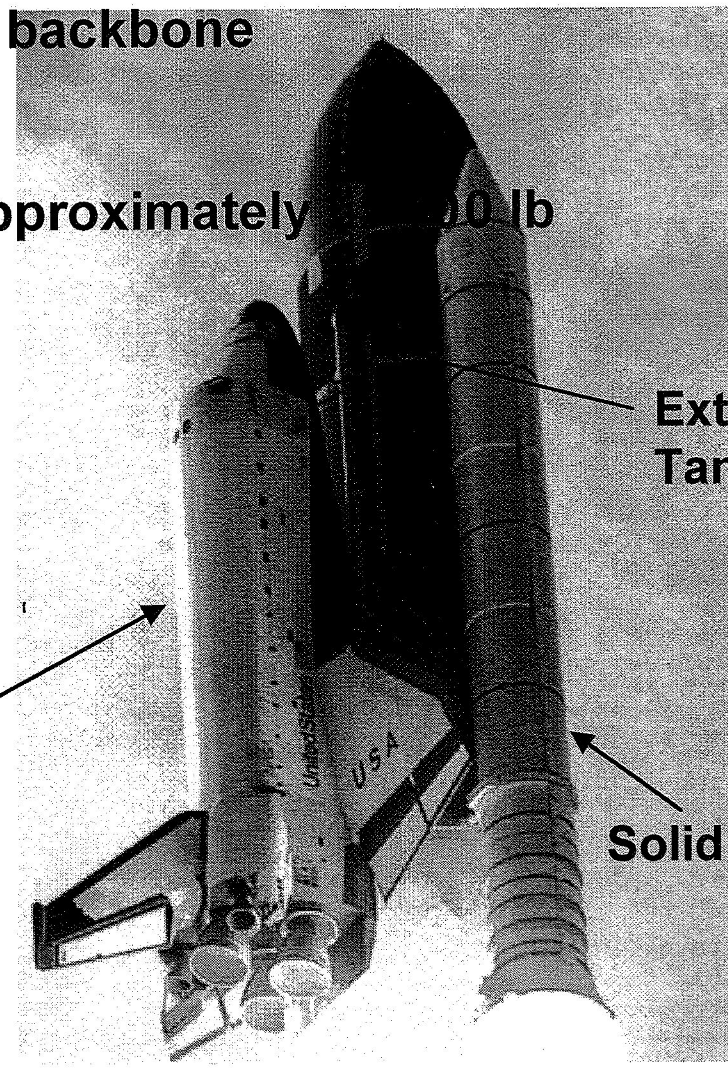
The External Tank (ET)

- Provides LO2 and LH2 propellants for the orbiter engines
- In addition, the ET is the structural backbone of the Space Shuttle assembly
- Light Weight Tank (LWT) weighs approximately [illegible]0 lb
- Primary alloys are 2219 and 2024
- Has over 3,000 feet of weld per ET



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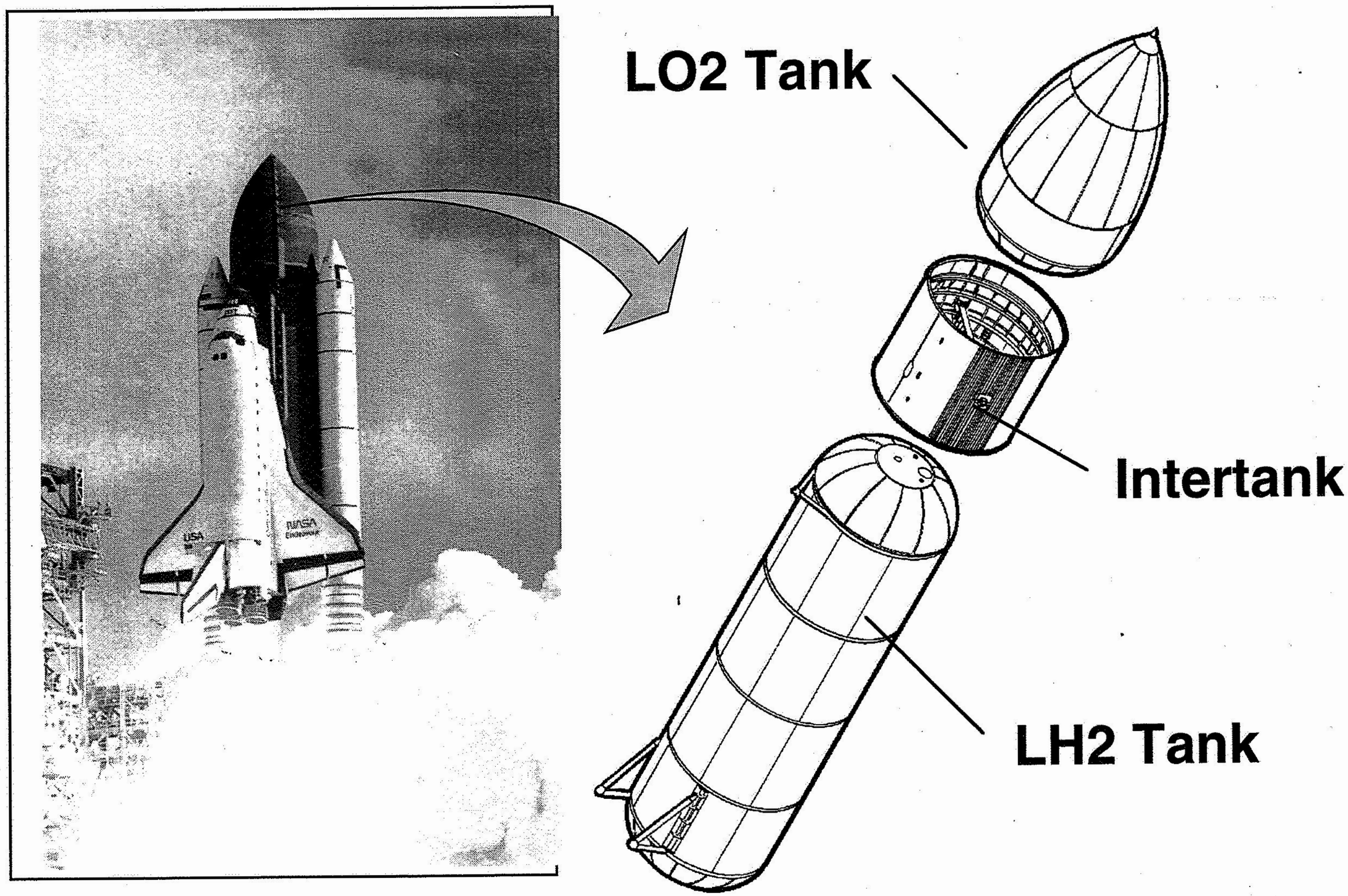
External Tank (ET)



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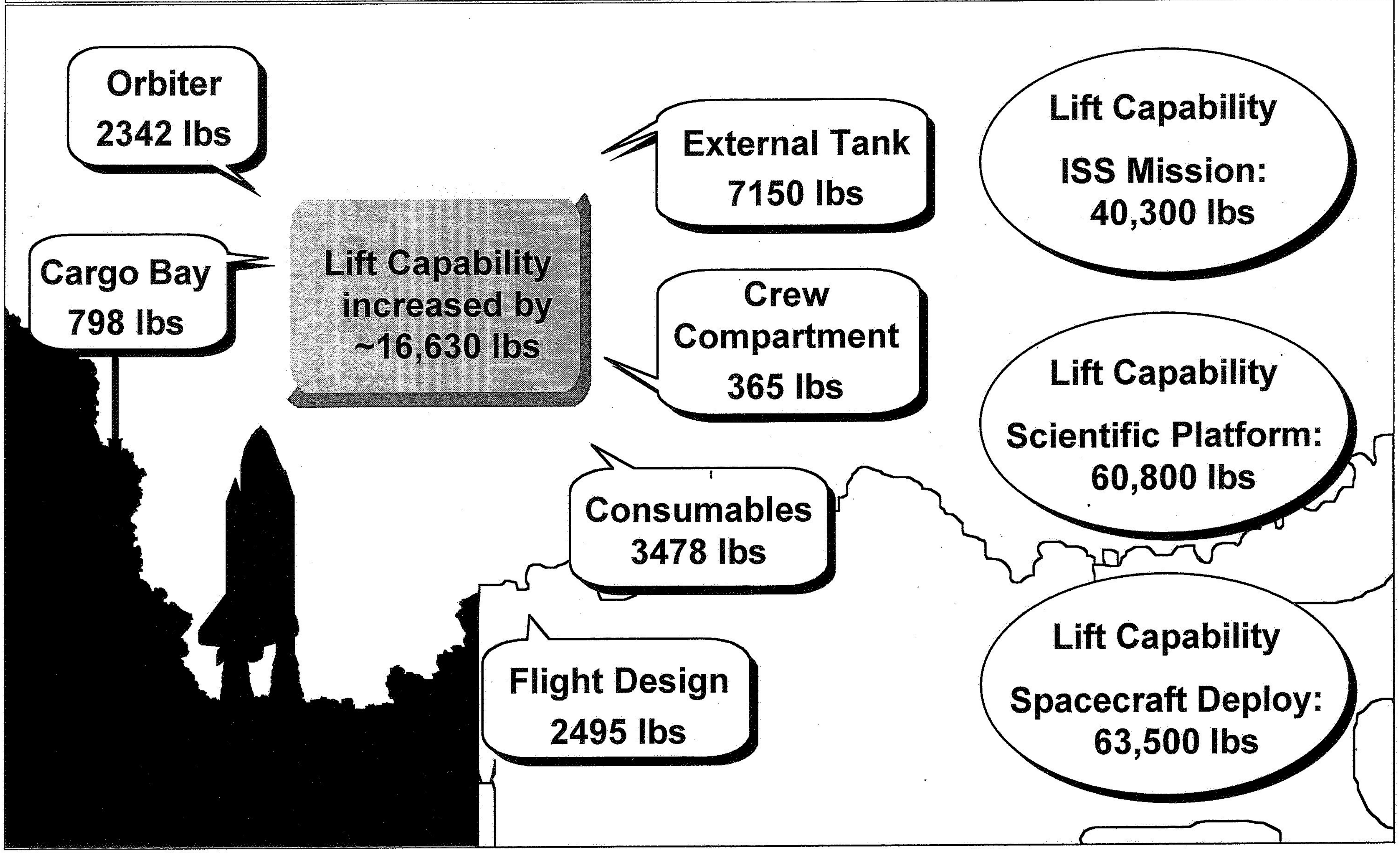
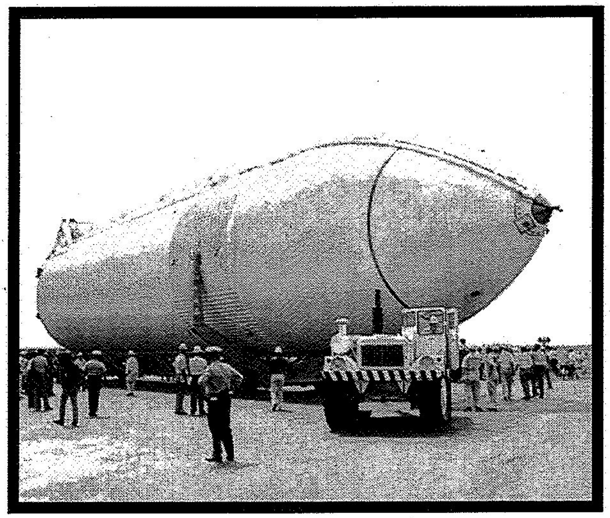
Space Shuttle

Lift Capability Improvement Contributors Since 1992

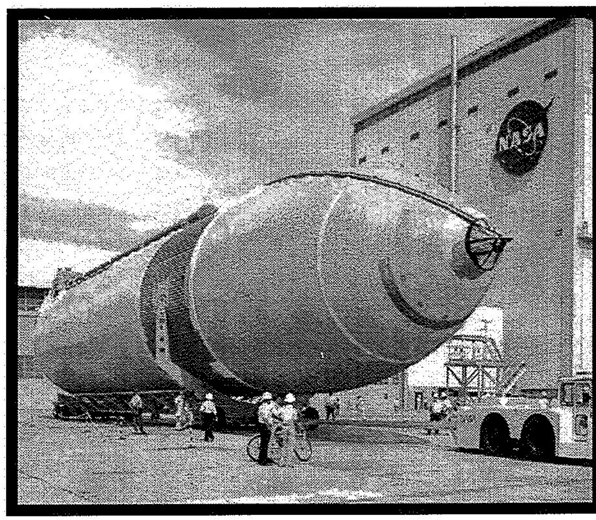


SLWT Heritage



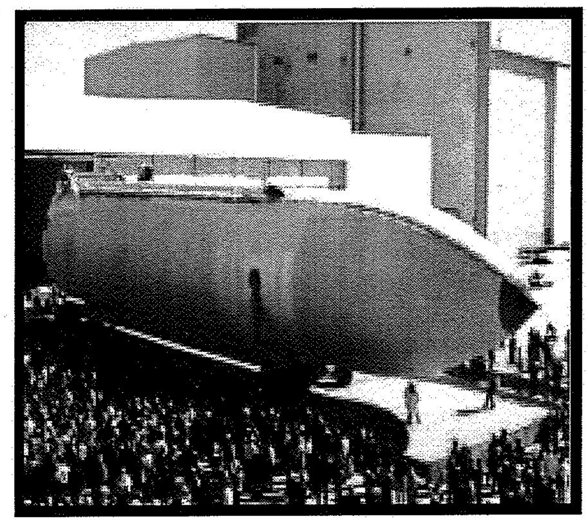
Standard Weight Tank
(SWT) - 75,569 lbs

6 Successful Flights



Lightweight Tank
(LWT) - 65,539 lbs

84 Successful Flights



Super Lightweight Tank
(SLWT) - 58,039 lbs

3 Successful Flights

25 Planned Flights

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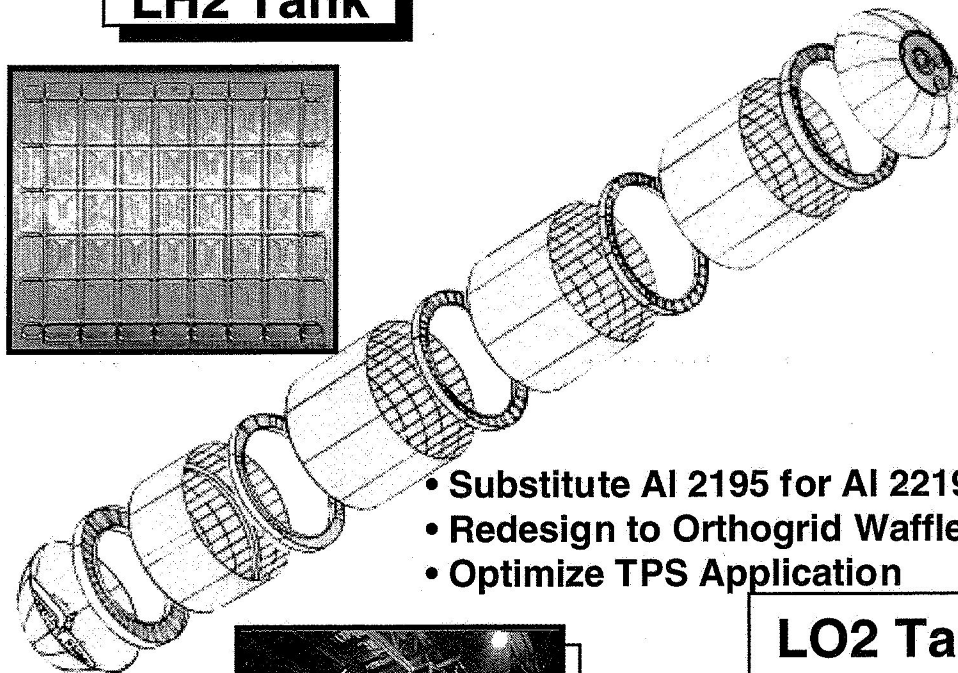
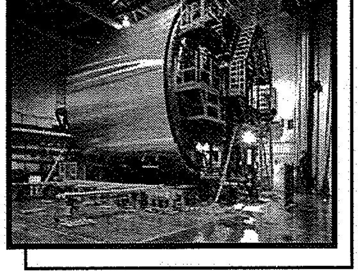
SLWT Configuration

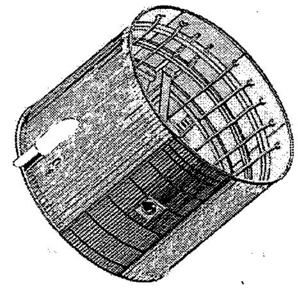
LH2 Tank

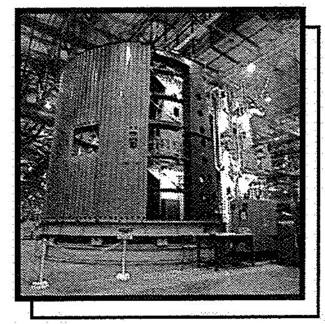


- Substitute Al 2195 for Al 2219
- Redesign to Orthogrid Waffle
- Optimize TPS Application



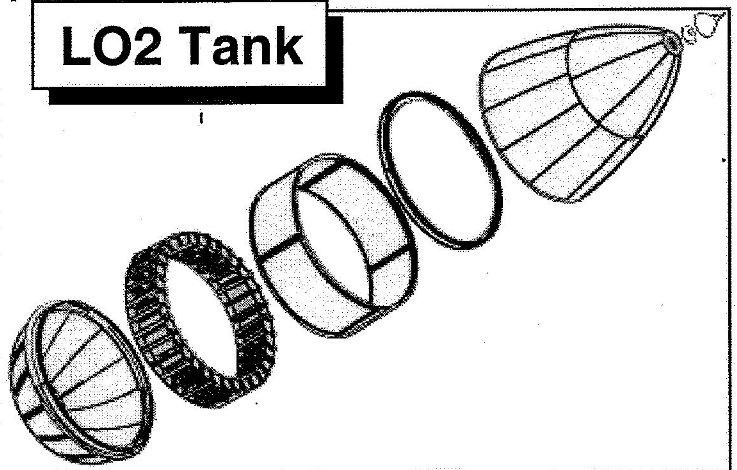
Intertank

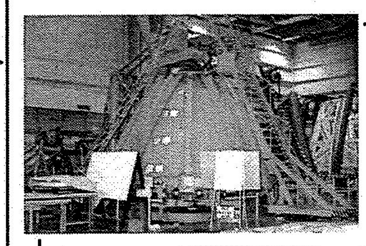




- Substitute Al 2090 for Al 2024 and Al 7075
- Machine TPS after Application

LO2 Tank





- Substitute Al 2195 for Al 2219
- Resize
- Optimize TPS Application

= Al Li 2090, 2195

= Other Redesigned Parts

= No Change

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Aluminum - Lithium 2195

Alloy goals were
- Higher strength than 2219
- Lower density
- No decrease in fracture toughness at cryogenic temperatures
- Weldable
- Formable

- Started off as 2219 plus 1.3% Lithium

- Issues with stress-corrosion, LOX compatibility, and weld repairs resulted in the following changes in composition:

  - 4% Copper
  - 1% Lithium
  - 0.4% Magnesium
  - 0.4% Silver

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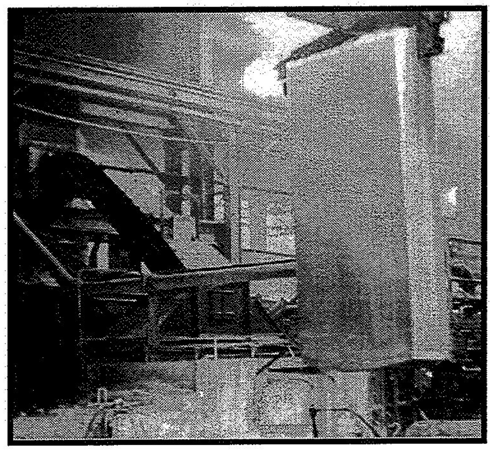
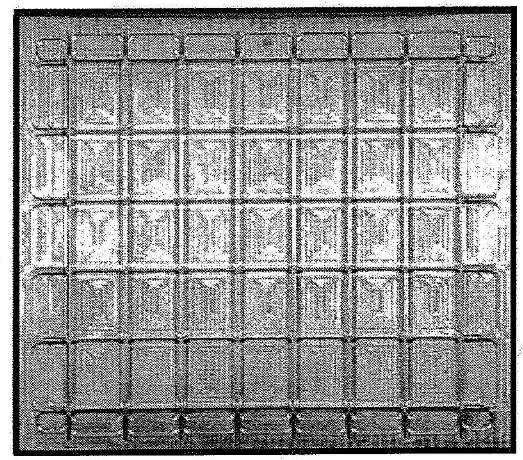
SLWT Key Technologies

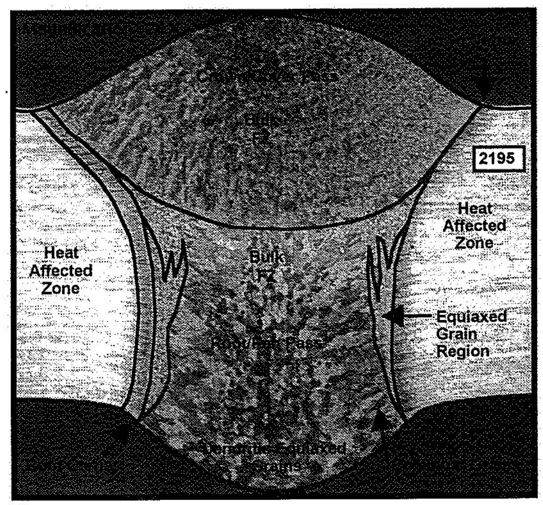




- Al 2195 (Aluminum-Lithium)
  - Successful Material Developed
  - Two Sources for the 2195 Material

- Al 2195 Forming
  - Spun Dome Cap
  - Stretched Formed Gore Panels
  - Bump Formed Barrel Panels

- Al 2195 Welding
  - Issues are Mitigated
  - Working to Increase Producibility



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SLWT Technology/History

- 1993 Weld Repair
  Solved by changing weld wire and repair techniques

- 1994 Parent Metal Properties Issues
  Solved by a Statistical design of experiment including composition, aging, and rolling practice.

- 1995 Weld Repair Residual Stress Issue
  Solved by mechanical stress relief.

- 1996 Downhand Welding Thickness Limitation
  Solved by welding process modification.

- 1997 Weld Intersection Cracking Solved by
  - Extrusion change from 2195 to 2219
  - Process change from Vertical SPAW to Vertical VPPA
  - Single Cover Pass to Dual Cover Pass

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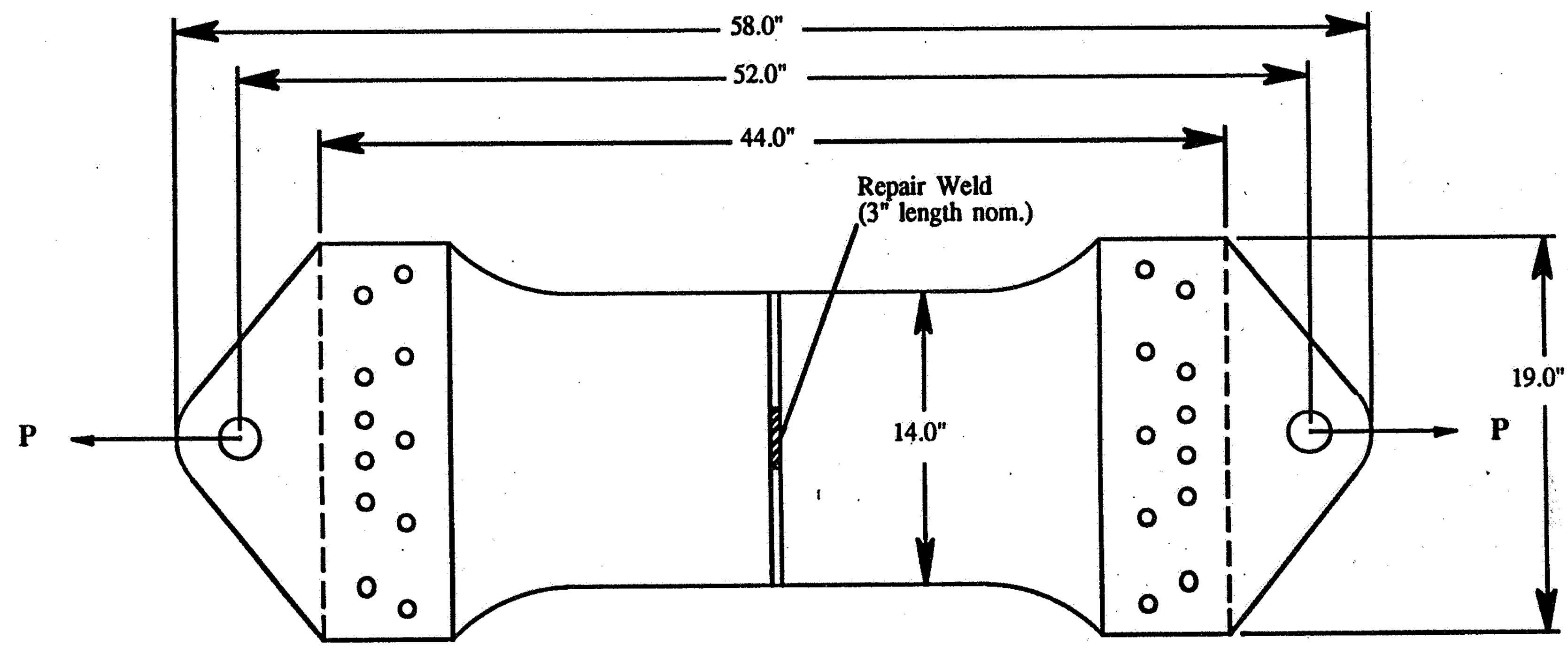
Test Procedure:

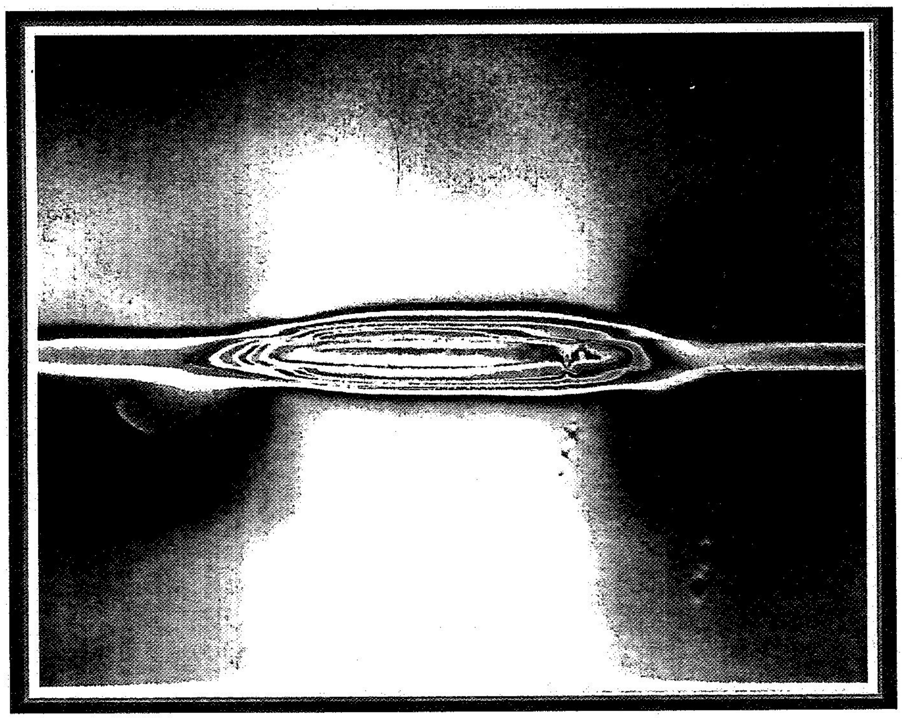
- 0.200" thick 14"x 44" welded dogbone specimen with single 3" long repair weld selected for baseline
    - Residual stress analysis and measurements guided choice of geometry



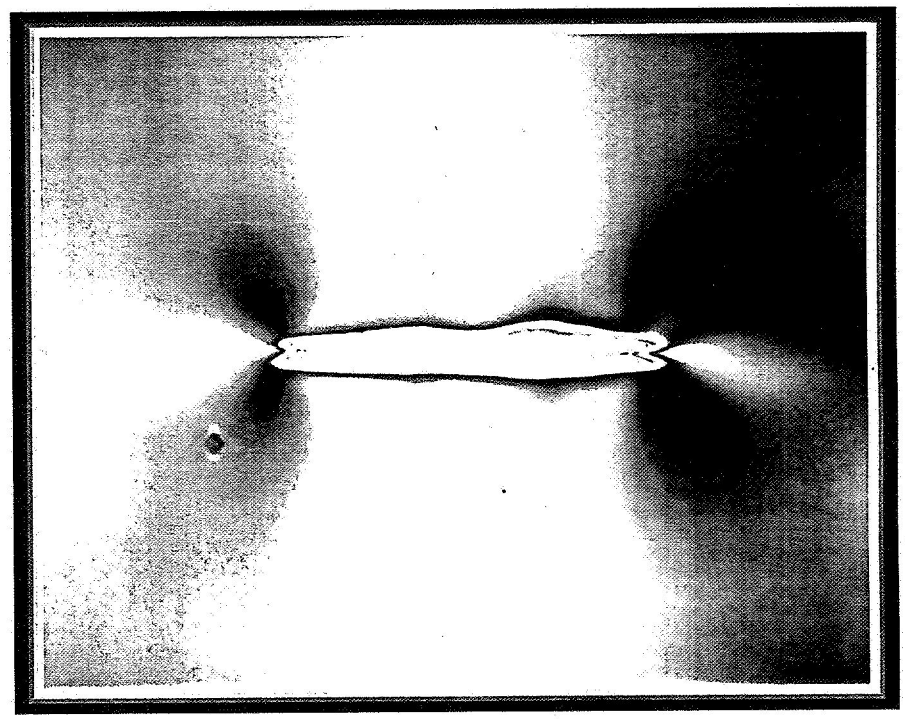
Specimen with Clevis Plates Attached

Test Results

- **Photoelastic results (cont'd)**



Aluminum Specimen

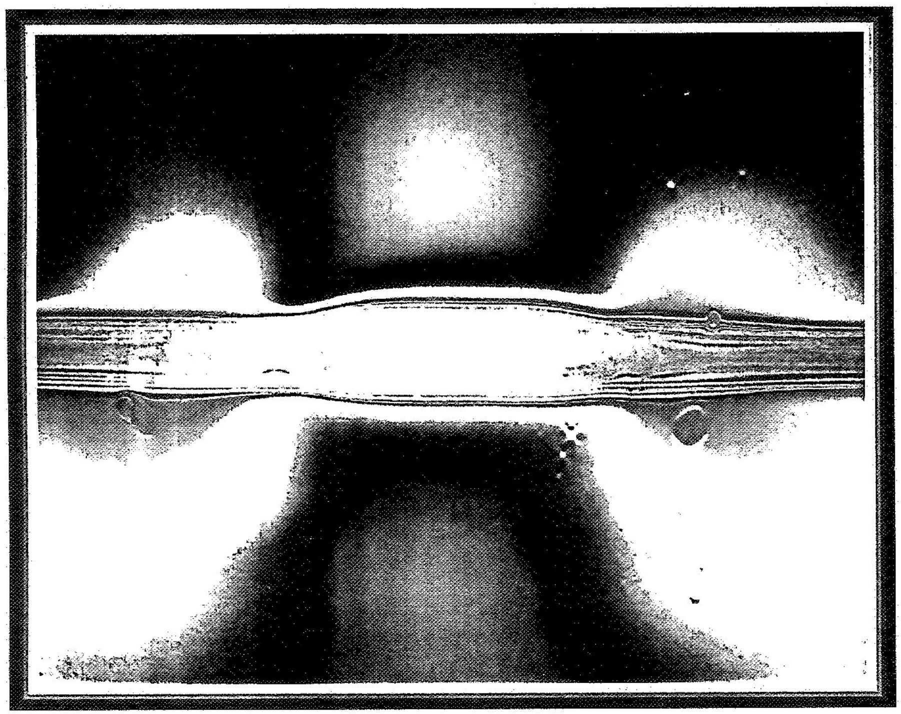


Al-Li Specimen

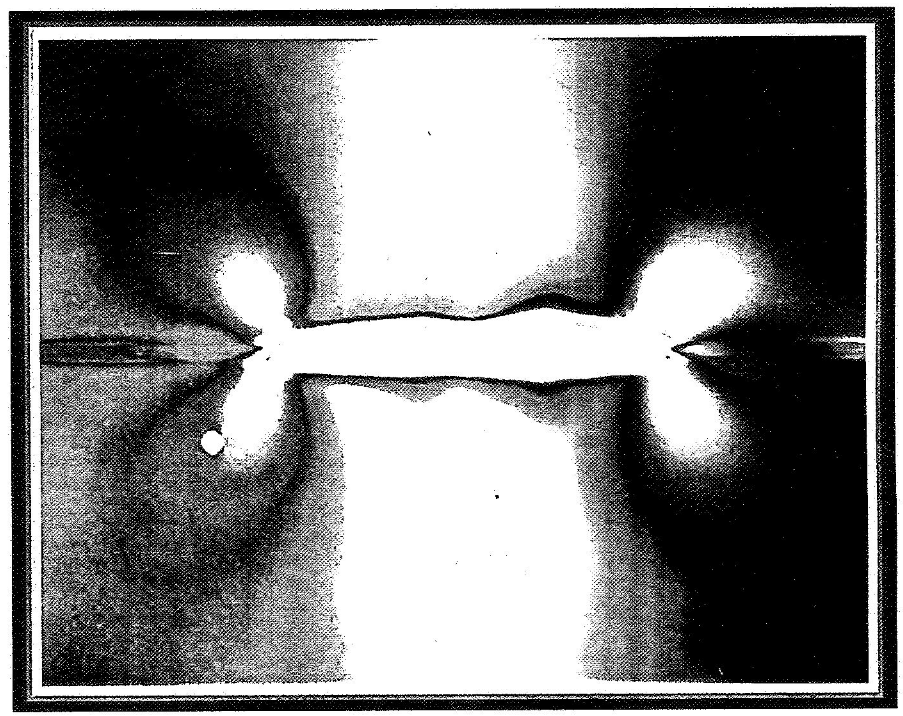
25 ksi

Test Results

- **Photoelastic results (cont'd)**



Aluminum Specimen
38 ksi

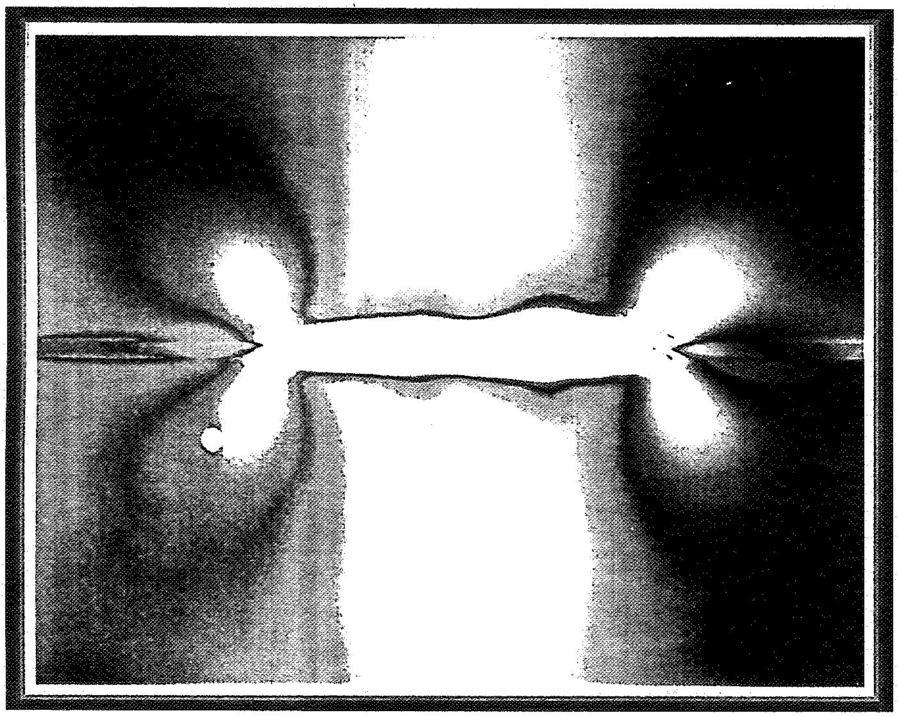


Al-Li Specimen
29 ksi

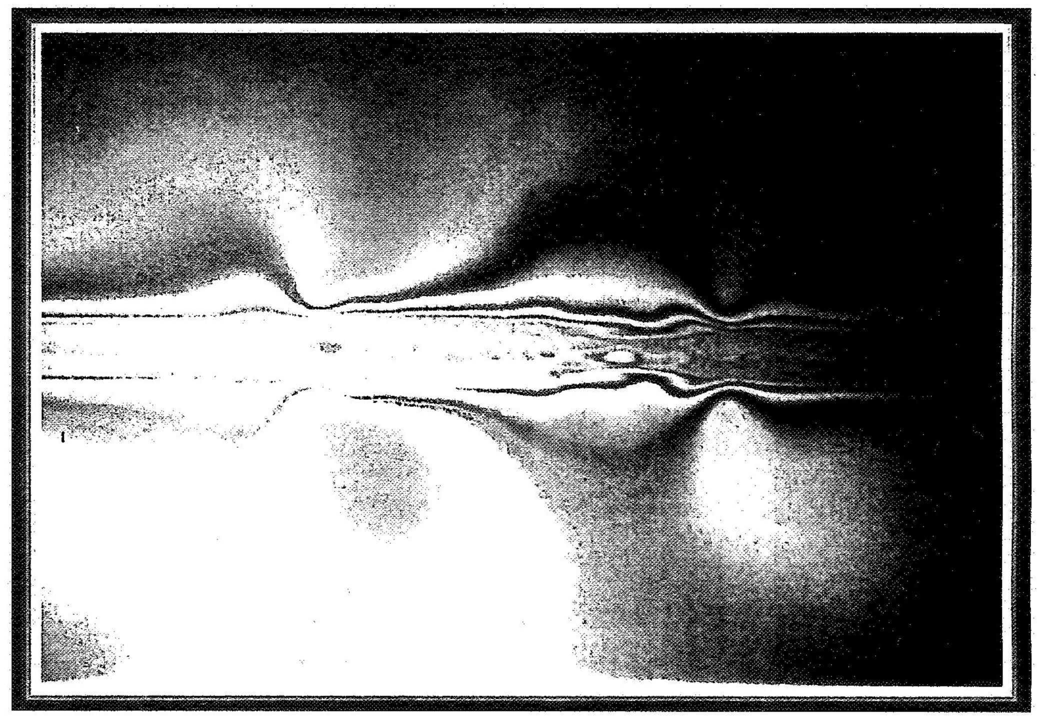
5-25641

Test Results

- **Photoelastic results (cont'd)**



Unplanished Specimen
29 ksi



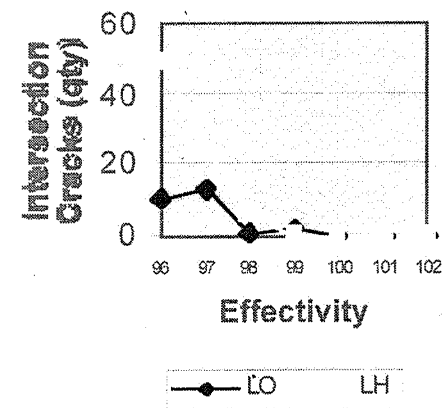
Planished Specimen
40 ksi

Intersection Crack Statistics

- All major intervention activities complete.
- Transition plan of remaining activities prepared and implemented

ET***	Tnk	Cracked Intersections				
		Prior to Proof	Post Proof #1	Post Proof #2	Post Proof #3	Tot
96	LO	3	8	0	0	11
	LH	30	17	2	0	49
97	LO	12	1	0	-	13
	LH	8	16	0	-	24
98	LO	0	1	0	-	1
	LH	0	6	-	-	6
99*	LO	1	1	-	-	2
	LH	0	0	-	-	0
100**	LO	0	-	-	-	0
	LH	0	-	-	-	0
101**	LO	0	-	-	-	0
	LH	0	-	-	-	0
102**	Lo	0	-	-	-	0
	LH	0	-	-	-	0

* Inspection/ work pending
** Welds pending
*** As built effectivities



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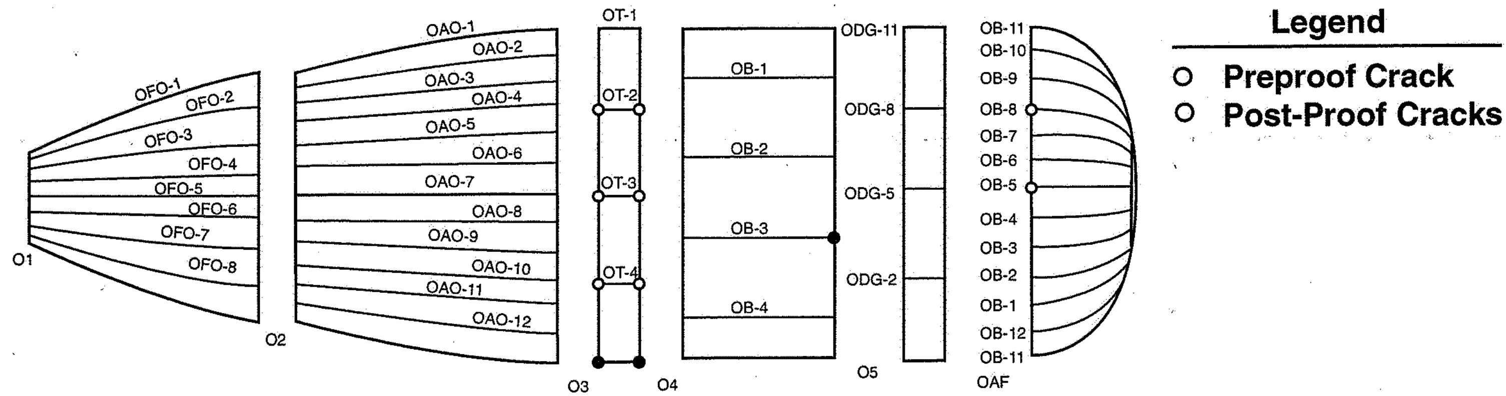
SLWT ET 96 Intersection Cracks (LO2)

Intersection cracks occurred on the longitudinal Al 2195-to Al 2195 and Al 2195-to-Al 2219 plate-to-plate and extrusion-to-extrusion welds during and after circumferential welding.



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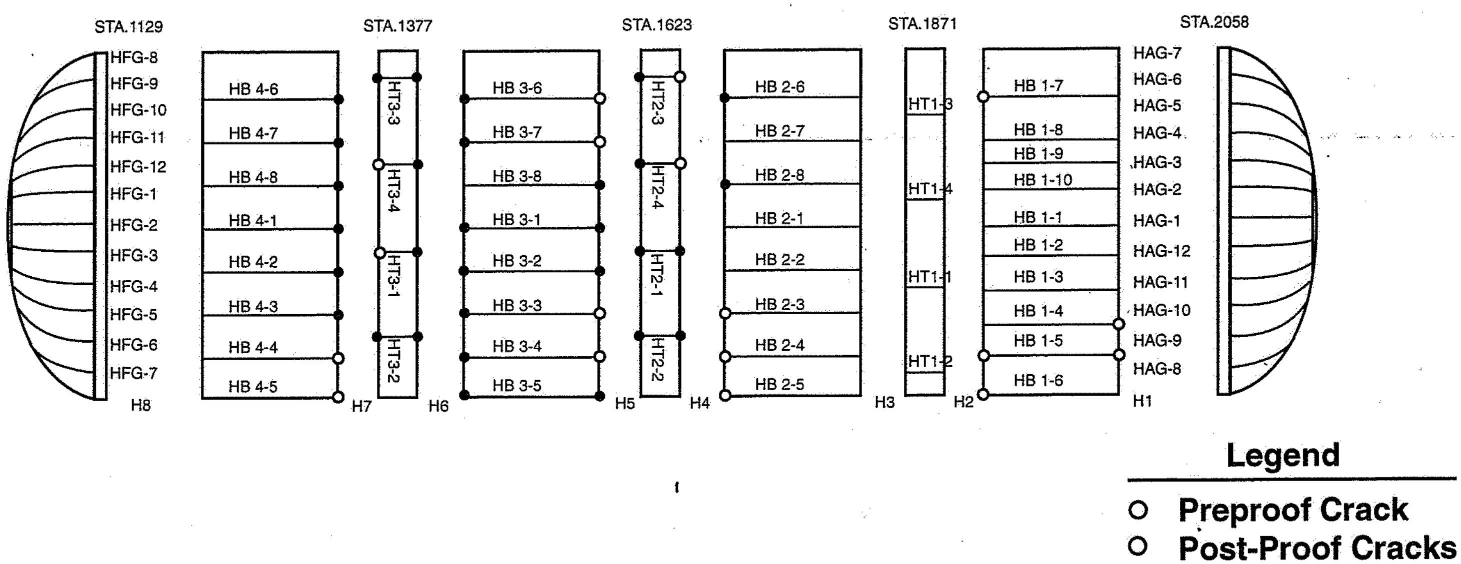

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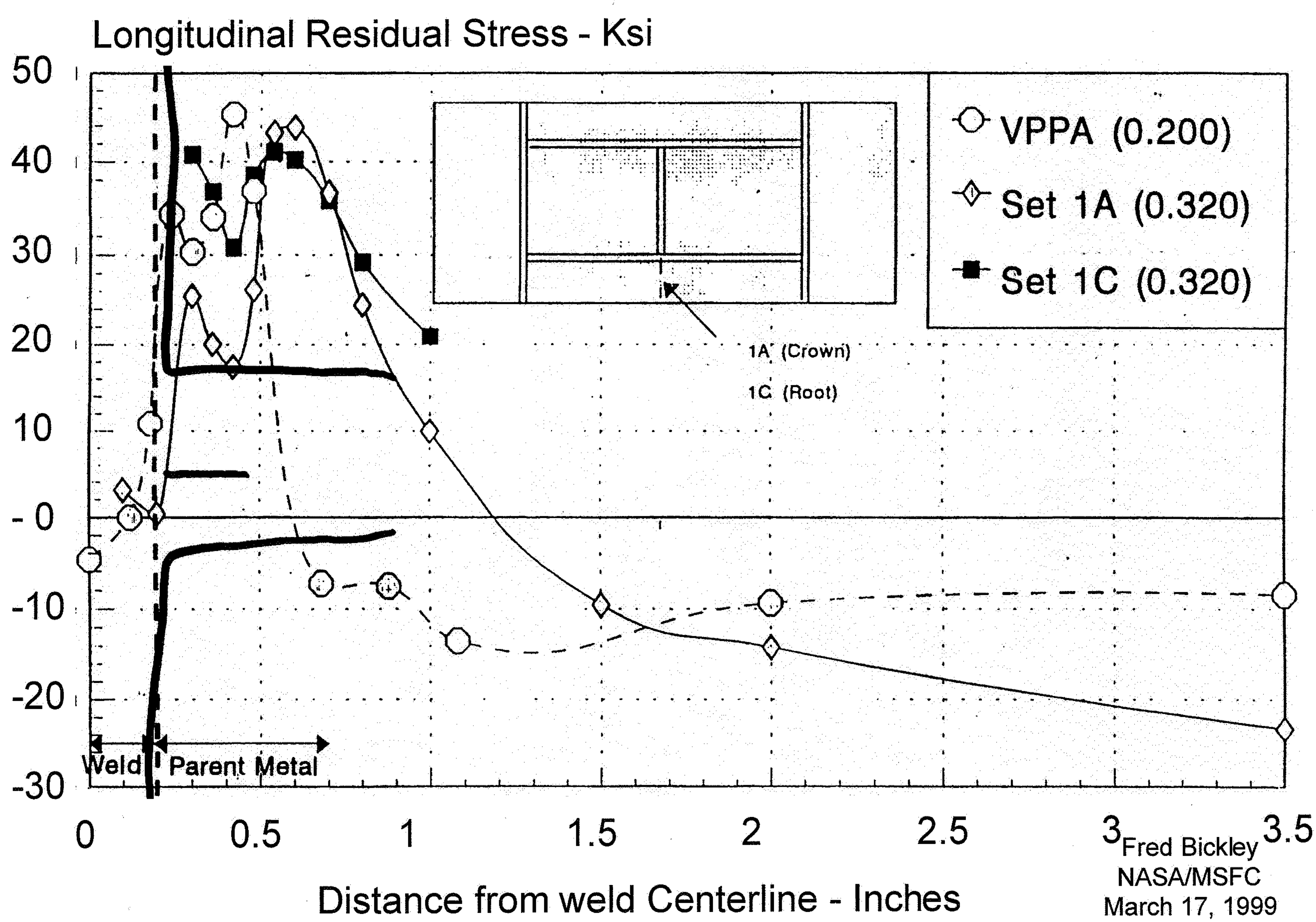
Residual Stress Measurements on Initial Welds Along A Line Perpendicular to Weld



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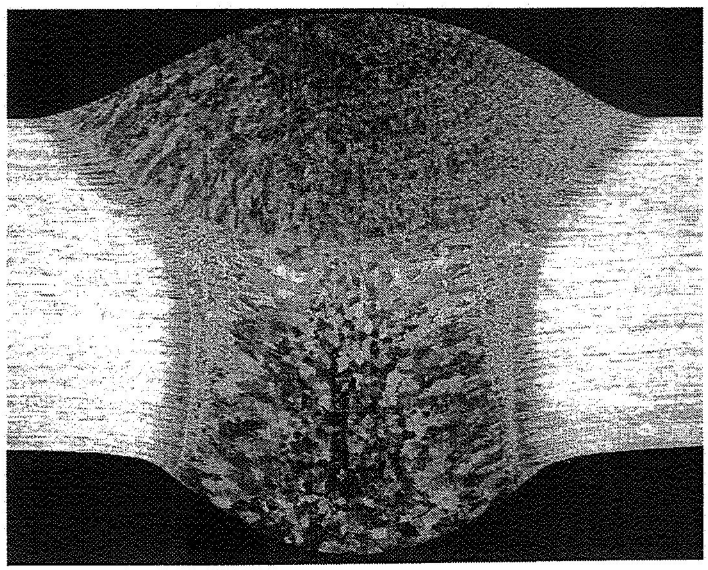
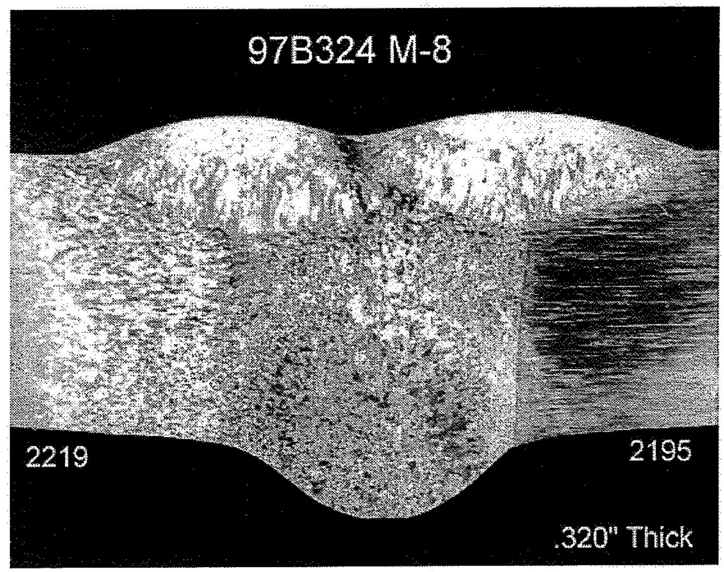
Photomicrographs of Single Cover Pass and Dual Cover Pass





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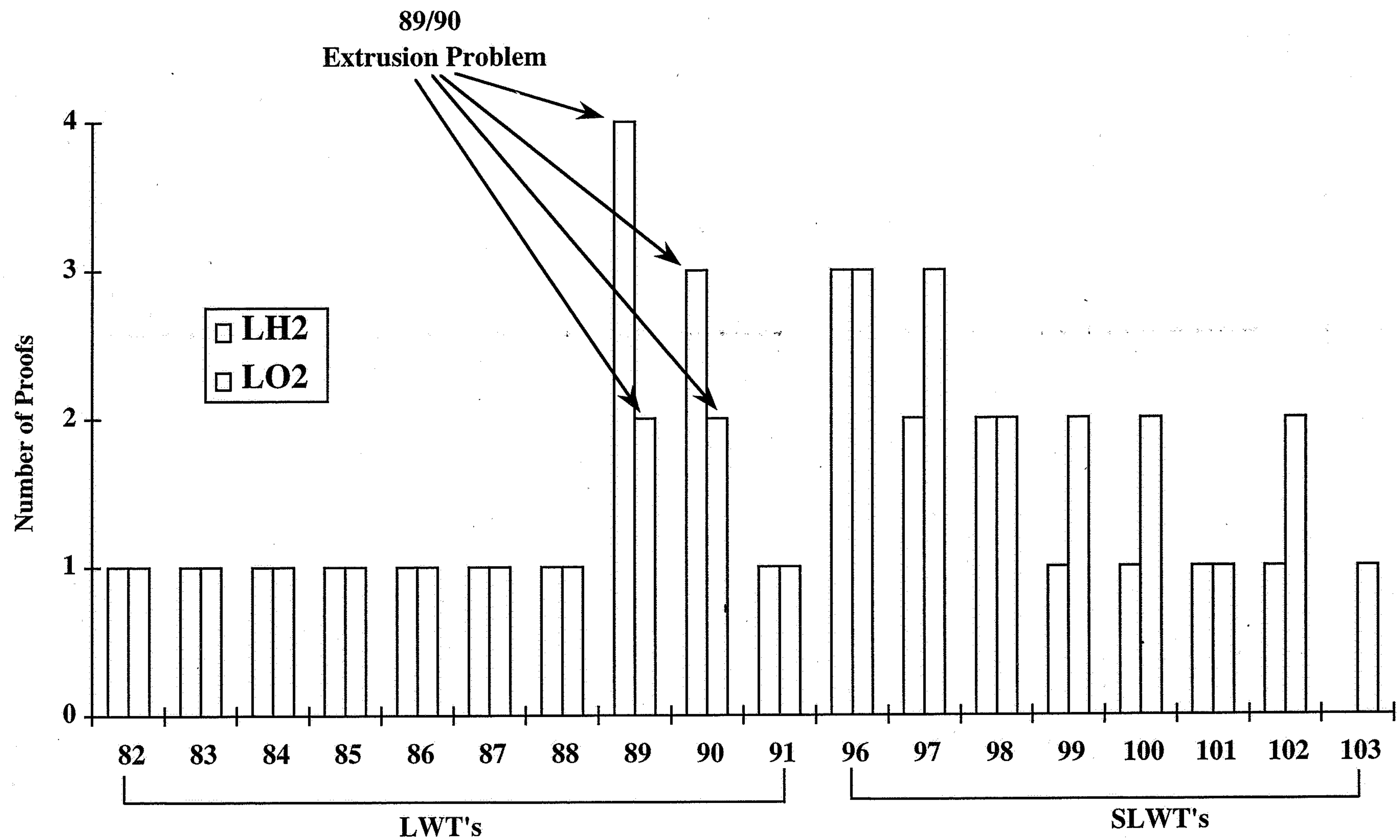
External Tank Number of Proof Test Per Tank



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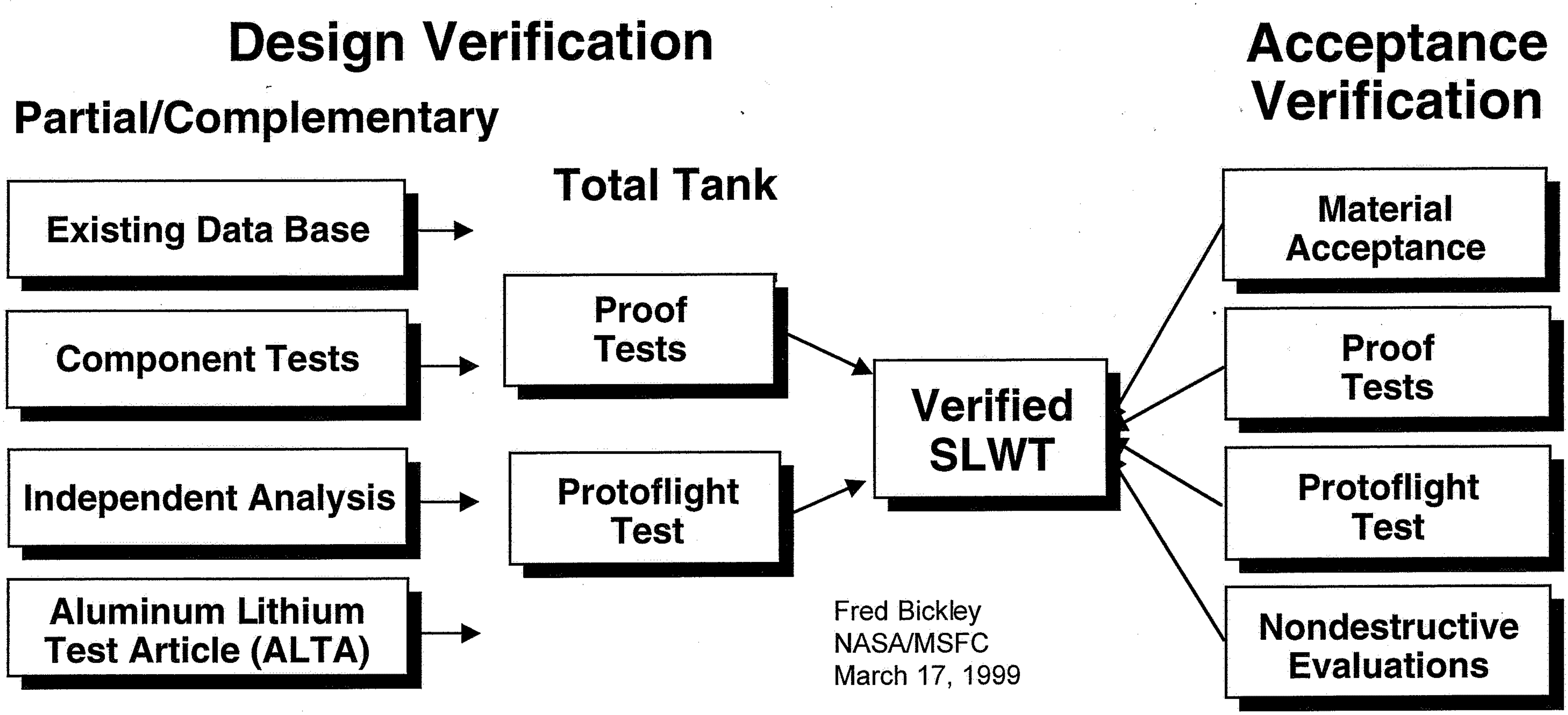
SLWT Verification

- Ground rule - all structural verification will be tied to either a test or flight history of the current LWT.

- Methodology - The team looked at each structural subassembly and their failure modes. Each failure mode had to be verified by a test or flight history.

- Result was an innovative, multifaceted verification program.



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SLWT Verification

- The ALTA testing included a series of test conditions.
  - * Five influence coefficient cases.
  - * One water fill and one HDF test of the LO2 aft dome.
  - * Four barrel panel load cases to limit, ultimate and capability load.
    - ~ Post Staging case , +Z axis panels
    - ~ Liftoff case , +Z and ±Y axis panels
    - ~ Two Prelaunch cases , -Z and ± Y axis panels
- The ALTA proved the adequacy of the LO2 dome stability and the robust design of the orthogrid barrel panels.

Flight Condition	Design Ultimate Load Condition		Capability Load Condition	
	Pressure (psi)	% of Limit Body Loads	Pressure (psi)	% of Limit Body Loads
Liftoff	17.6	140	17.6 9.6	175 140
Prelaunch	0.0	129.5	0.0	162
Post Staging	31.8	126.5	31.8 20.0 * 9.5 **	146 126.5 126.5

* Denotes approximate condition at which non-linearity was observed in the gages.
** Denotes condition at which final collapse occurred.

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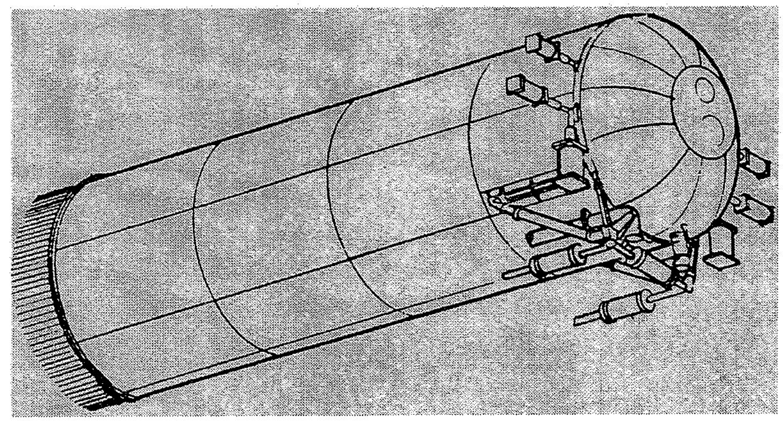
SLWT Verification



- Protoflight Tests
  - Every LH2 tank will be protoflight tested to 115% design limit load for two test conditions.
    - * Stability of the longeron region in barrels 1 and 2.
    - * Stability of the aft dome.
  - SLWT-1 was heavily instrumented during its' protoflight testing and provided excellent correlation to analytical predictions.
  - Protoflight testing represents additional risk to the program compared to the LWT testing.
  - Risk is confined to the ground testing.

- Proof Tests
  - Every LO2 and LH2 tank is proof tested.
    - * LO2 proof is an ambient temperature hydrostatic test with the addition of a vacuum under the aft dome.
    - * LH2 proof is a ambient temperature gaseous nitrogen test with mechanical loads applied at the aft Orbiter and Solid Rocket Booster interfaces.

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SLWT Verification

- SLWT proof testing applies the same philosophy as used for the SWT and LWT.
- Proof tests are fracture based, i.e. they verify workmanship and ensure that the design has not been invalidated by the presence of an undetected flaw.
- Fracture Based Proof Test
  - Designed to prove that any undetected flaw will not grow to a size which will cause failure within four mission lives of the tank.
  - Ambient temperature proof stress is adjusted for the fact that the material is tougher at cryogenic conditions.
  - Material testing is performed on each plate of material to ensure required fracture properties.
  - Post proof Non-Destructive Evaluation (NDE) is required for all welds not fully tested to the required stresses.
  - The fracture based proof tests also provide excellent strength tests, demonstrating each tank pressure wall to >112% of limit load for the LH_2 tank and >117% of limit load for the LO_2 tank.

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Verification of Design Properties

- Since 2195 allowables are not available from the MIL-HDBK-5, the SLWT Project has implemented a series of concurrent test programs.

- Parent Metal

  1) Expanded lot acceptance testing, including fracture testing
  2) Witness coupons from flight hardware
  3) First article cut-ups
  4) Separate characterization test program for lot-to-lot variations, temperature effects, bearing, shear, etc.

- Weldments

  1) Weld schedule development test data
  2) Weld tool certification data
  3) Weld tool verification panel tests
  4) Allowables test program

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Material Property Data Base

•Strength allowables for parent material, initial welds, and repair welds have been generated.

* Over 9000 tests on parent plate material with approximately 25% at cryogenic temperatures.

* Over 1800 tests on 2195 extrusion with approximately 25% at cryogenic temperatures.

* Over 10,000 tests on initial welds with approximately 30% at cryogenic temperatures.

* Over 625 repair weld wide panels with approximately 35% at cryogenic temperatures.

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SLWT Verification Summary

- An aggressive, innovative, test based design verification program was established, and has been executed, for the SLWT project.
  - ALTA, protoflight testing, and design ground rules for stability of LH2 Tank.
  - ALTA, design ground rules, and independent analysis for stability of LO2 Tank.
  - Proof Tests for fracture control and strength of LO2 and LH2 Tanks.
  - Component tests and independent analysis for stability of Intertank.
  - Component tests for frames and substructures.
- Rigorous workmanship acceptance program consisting of material acceptance testing, proof tests, and NDE, has been established and is being executed.
- The SLWT verification program has undergone many independent reviews, both internal and external to the agency.
- Design testing has been completed and was highly successful.
- Three Have Flown Safely and Succesfully

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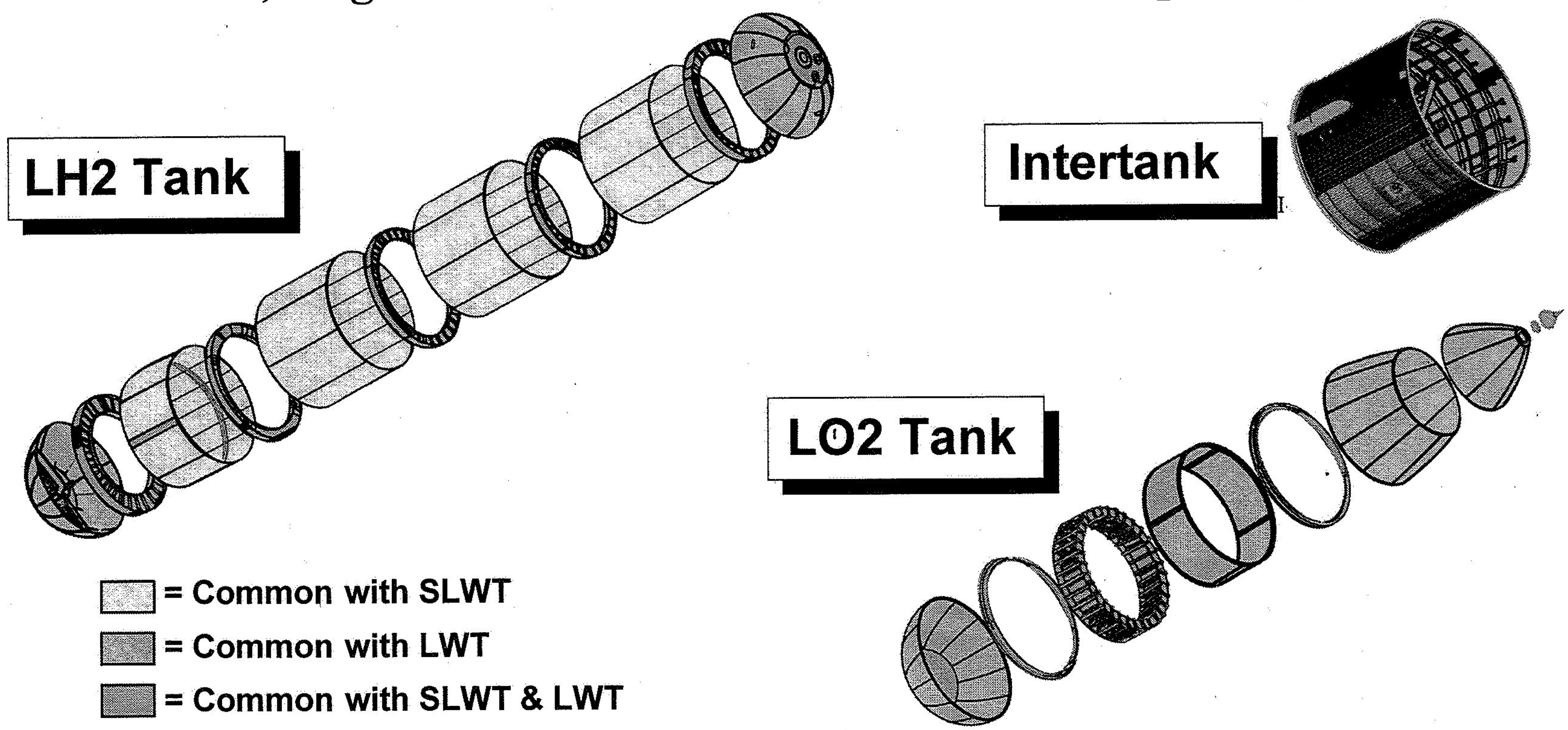
Augmented Light Weight Tank (ALWT)

Augmented Lightweight Tank Prime

Heritage:

- 2195 LH2 tank barrel panels => Same as Super Lightweight Tank
- 2219 LH2 domes and LO2 tank => Same as Lightweight Tank
- Intertank, ringframes & slosh baffle => Same as Super Lightweight Tank



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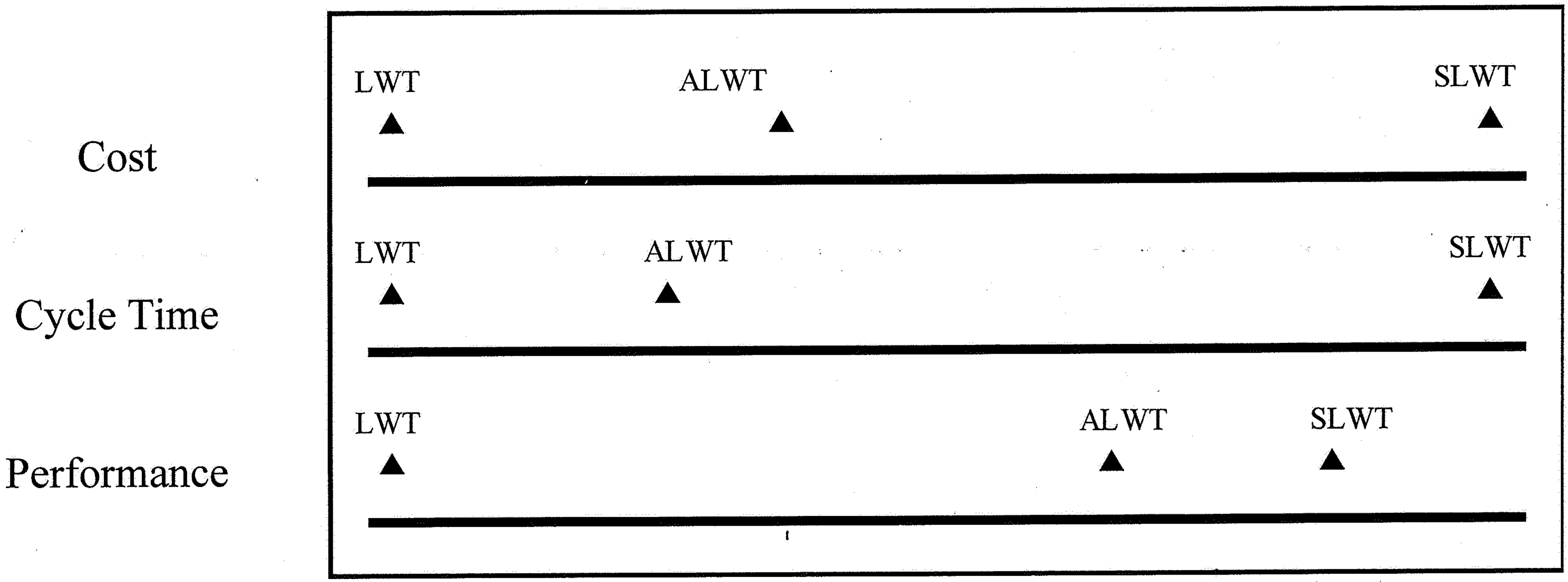
Benefits of ALWT



Augmented Lightweight Tank Prime provides the program with maximum flexibility by combining existing designs for optimum performance vs. cost and producibility.

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Conclusions

The External Tank Project has Successfully Transitioned from the LWT Design to the SLWT Design Providing 2/3 of the Weight Savings Required to Place the Space Station in the 51.6 Degree Orbit.

Completed 10 SLWT LOX and 10 SLWT LH2 Tanks through Major Weld.

Successfully Completed Proof Test on 7 SLWT LOX and 8 SLWT LH2 Tanks.

The Heritage of the External Tank Continues to Be One of Successfully Meeting its Cost, Schedule, and Technical Goals.

The Development of the SLWT was Completed 20 Million Dollars Under Budget.

The First SLWT Was Flown Successfully on June 2, 1998.

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